Digital Electronic Communication between ICU Ventilators and Computers and Printers

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Introduction

When one ventures onto the exhibit-hall floor to 'kick the tires' of this year's latest and greatest ventilators, on almost all of them one sees communication ports designed to allow computers in the ventilator to 'talk' to external devices such as printers and other computers. If this feature is not included on a current model, then it usually is available as a low-cost option. The ventilator sales staff will eagerly point out this "valuable" feature and will be quick to imply that everyone needs this digital communication port in order to exist in the "modern computerized hospital environment." The clear impression given is that if you buy this elegant machine, all you need to do is make a simple connection between this port and any other computer, and all the necessary respiratory care data will be effectively and accurately transferred.

In reality, the current situation is more like buying a fancy new car, then finding that the radio receives only Japanese stations. If you are an electronics expert, you might be able to modify the radio to receive your local FM stations. It might be possible to buy a converter that fixes the problem; or you might accept the radio the way it is and learn Japanese. Most persons would just never use the radio, and that is exactly what happens with most of the digital communication ports on mechanical ventilators today. They sit unused.

The purpose of this paper is to provide a background on digital electronic communication and the problems encountered in interfacing a computer with a mechanical ventilator. The current state of the art and future directions are examined. Finally, three pivotal questions are addressed: (1) Is it essential to have a digital electronic communication

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port on a ventilator? (2) What impact do electronic data from a ventilator have on patient outcome? (3) If electronic communication is to be effective in the future, how should these interfaces be configured for mechanical ventilation?

Background

Digital communication of respiratory care information can be seen as having five hierarchical levels (A through E), as seen in Figure 1. The lowest level (A) is the basics of the hardware, the physical communication link. The intermediate levels are (B) handshaking between devices, (C) data format, and (D) validation of data. At the top level of this hierarchy is (E) the issue of whether data are representative. Effective communication on all these levels is essential if the system as a whole is to be beneficial to the clinician and to the patient.

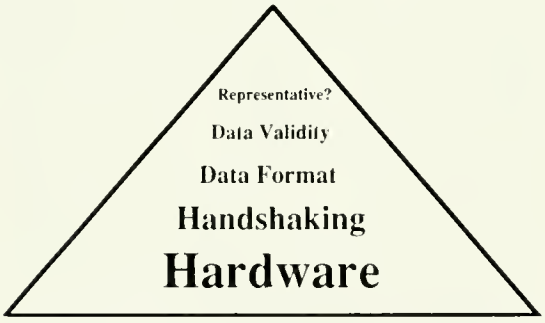

Fig. 1. The five levels of digital communication. Effective communication must exist at all five levels if electronic communication between the ventilator and the computer is to be helpful to the clinician.

Level A: Hardware for Digital Communication

The lowest level of our hierarchy is the hardware necessary to communicate digitally. Digital communication consists of representing numerals and letters by binary numbers. Each numeral and letter is assigned an ASCII (American Standard Code for Information Interchange) code number. These ASCII codes are represented by binary numbers that are made up of series of the numerals one (1) and zero (0). For example, the numeral 1 (actually considered a character for ASCII purposes) is assigned an ASCII value of 48, which when converted to base 2 or a binary number is 110000 ($110000 = 2^5 + 2^4$).

The most common digital communications on mechanical ventilators conform to a standard known as RS-232 (Fig. 2). The ASCII numbers are sent as a series of either seven or eight data bits (a 1 or a 0). Each bit is physically represented by a voltage (+3 to +25 V for a 1, and –3 to –25 V for a 0) that is present on the wires for a fixed time interval. The length of the fixed time interval for each bit is dependent on the baud rate (bits per second). Many different baud rates are used, from 100 to 19,200 bits per second. The RS-232 standard also defines 25 conductor cable wiring connections (Table 1) that can be used for RS-232 communication. A common mistake is to assume that if a device is claimed to have an RS-232 port, it will easily connect with any other RS-232 port on a computer or printer. The problem with the RS-232 standard is that it is very flexible—to the point of being close to being no standard at all. We like to refer to this phenomenon as the RS-232 myth.

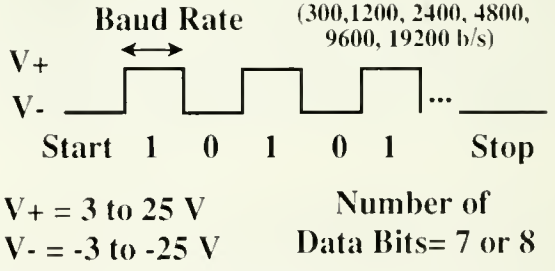

Fig. 2. RS-232 digital communication, the most common digital communication on mechanical ventilators. The ASCII numbers are sent as a series of either seven or eight data bits (a 1 or a 0). Each bit is physically represented by a voltage (+3 to +25 V for a 1, and –3 to –25 V for a 0) that is present on the wires for a fixed time interval. The length of the fixed time interval for each bit is dependent on the baud rate (bits per second). Many different baud rates are used, from 100 to 19,200 bits per second.

The following are common variables associated with the RS-232 standard: cable connector, connections (pin definitions), number of data bits, number of stop bits, baud rate, and parity. Parity is a bit used for error-checking. It must be defined whether

Table 1. RS-232 25-Pin D-Connector Pin Definitions

Pin No.	Symbol	Definition
1	FG	Frame Ground
2	TD	Transmitted Data*
3	RD	Received Data*
4	RTS	Request To Send
5	CTS	Clear To Send
6	DSR	Data Set Ready
7	SG	Signal Ground*
8	DCD	Data Carrier Detect
9		
10		
11	QM	Equalizer Mode
12	sDCD	Secondary DCD
13	sCTS	Secondary CTS
14	sTD	Secondary TD
15	TC	Transmitter Clock
16	sRD	Secondary RD
17	RD	Receiver Clock
18	DCR	Divided Clock Rcvr
19	sRTS	Secondary RTS
20	DTR	Data Terminal Ready
21	SQ	Signal Quality Detect
22	RI	Ring Indicator
23		Data Rate Selector
24	TC	Ext Trans Clock
25		Busy

*Indicates essential connections.

parity error-checking is used, and if it is used whether it is even or odd parity.

The electrical connector varies a great deal from device to device. The number of conductors in the cable can vary from 2 to 25. The types of connectors used include RJ-11 phone jack, DIN-8 round connector, 9-pin D-connector, 15-pin D-connector, and 25-pin D-connector. These connectors may be male or female. The definitions of the pins vary among manufacturers. For example, the connections for the digital communication port on the Apple Macintosh computer are shown in Table 2.[1] Compare Table 2 to Table 1, which is the RS-232 standard.

Even the definitions of "transmit" and "receive" are confusing. The manufacturer of a computer may define data going from his computer to the ventilator as "transmit" and data from the ventilator as "receive." The ventilator manufacturer, on the other hand, might define data going from the ventilator to the computer as "transmit." In such a situation, if the user connects "transmit" from both devices together, there is no communication because both devices are 'talking' and neither is 'listening.'

Table 2. Digital Communications Port on Apple Macintosh Computer*

Pin	Definition
1	Handshake Out
2	Handshake In
3	Transmit Data –
4	Signal Ground
5	Receive Data –
6	Transmit Data +
7	General Purpose Input
8	Receive Data +

*The connector is a DIN-8 microcircular connector.[1]

The number of data bits and stop bits, the baud rate, and parity information on a device can usually be set by the user, and one must match all these variables if communication is to occur. Some more sophisticated devices automatically adjust these variables to adapt to the device connected to them. Unfortunately, the truth is that even on the simplest level of digital communication, the hardware level, there is often a major communication gap.

Level B: Handshaking between Devices

The second level of digital communication is handshaking between devices. This can be viewed as the stoplight of electronic communication. The whole idea is to control traffic flow between the devices. If data are being sent to a device more rapidly than it can deal with them, the device needs a way to say "STOP! Wait until I am ready!" This is known as handshaking.

Two different general schemes exist: hardware handshaking and software handshaking. Hardware handshaking uses physical wires between the devices, such as data terminal ready (DTR), clear to send (CTS), and request to send (RTS) to control the flow of information. The disadvantage of hardware handshaking is that it requires larger connectors and more conductors in the cable. It can

also be challenging to discover which connections are required for each device. The most popular technique is software handshaking, in which the only connections between the devices are transmit, receive, and signal ground. All the control of traffic is accomplished by use of special ASCII codes known as XON and XOFF, roughly equivalent to GO and STOP, respectively.

The handshaking must match on the two devices. If one device requires hardware handshaking and the other device supplies only software handshaking, there will be serious problems and unreliable communication. If hardware handshaking is used, it will be challenging to discover which connections are required for each device.

Level C: Data Format

The representation of the data is the third level of digital communication. The following is an example of the data stream from two different mechanical ventilators that are set up identically.

Ventilator 1: "Tidal volume = 350 mL"
Ventilator 2: "0.289"

The difference is that Ventilator 1 provides some verbal material to identify its value, and Ventilator 2 does not. In addition, Ventilator 2 uses liters rather than milliliters as the unit of measurement, and the tidal volume has been corrected for tubing compression-volume losses. Any computer interfaced with these two devices would have to deal with these supposedly identical data in two different manners. In order to communicate effectively, we must compare apples to apples and oranges to oranges. The sequence of variables and the format of the data stream must be carefully defined. All the units used should be the same, and any corrections should be consistent throughout. A frustrating fact has been that some medical device manufacturers have altered the structure of their stream of digital information from one version of their system software to another version. For example, a Puritan-Bennett (P-B) 7200 ventilator that has a pressure-control option installed will have a different data stream from a P-B 7200 that does not have that option. This third level of digital communication—data format—does not pose a tremendous problem if only one specific ventilator is to be interfaced with a computer. However, if more than one type of ventilator is used, accommodating all the different representations of data can be overwhelming.

Level D: Data Validation

The fourth level of digital communication is validation of the data. If the data sent from the ventilator are not valid, then it is impossible to transfer effective respiratory care information to the clinician. Validation involves checking all the data to make sure they are reasonable. For example, tidal volumes of 10 mL probably are not valid and should not be sent from the ventilator. This level of communication is essentially missing from all mechanical ventilators on the market as this paper is being written (early 1992).

A main reason that data are sent out by ventilators with no attempt being made to validate them is legal liability. Manufacturers are worried that if their devices make an interpretation of data, they can be potentially liable for missing data or bad data that in some way harm a patient. Although this is a very real concern, sending nonvalidated data may also be misleading and potentially cause harm. It seems that tradition has dictated that it is all right to display invalid information on meters and digital displays, and that therefore this is the safest legal path. We will never have successful electronic communication until we have solved this legal issue. There is no doubt that, in the long run, having high quality, validated data is in the patient's best interest.

Level E: Representative Data

The most important issue for medical decision making is whether the data are representative of the patient's state (Fig. 3). This is the highest level of digital communication. Only data that are truly representative should be sent from the ventilator. Figure 4 illustrates the problem. The raw data supplied from the ventilator at 10-second intervals have wide variability. There is also an immense quantity of information. For example, we obtained about 1,500,000 bytes (characters) of data from a P-B 7200 ventilator over a 24-hour period for one patient. This is equivalent to approximately one

fourth the length of the Bible. This vast amount of data definitely produces information-overload for the clinician at the bedside. It certainly is not reasonable to just dump all these data on clinicians and expect them to use the information effectively.

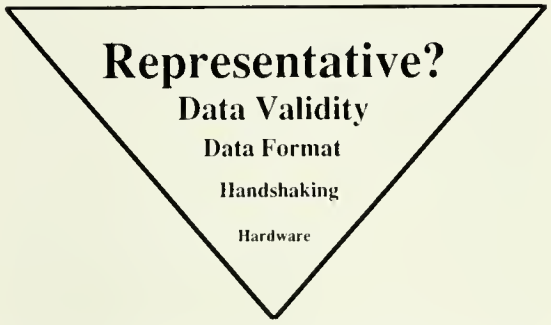

Fig. 3. The relative impact of the five levels of digital communication on medical decision making.

The data in Figure 4 were validated and represent actual patient events. Very few of these fluctuations are charted at present in the manually kept patient record. This raises questions: What is important to record? How often should data be recorded? What constitutes an artifact? How can you tell what is a significant event? We presented a collection of graphical raw data recordings to respiratory therapists, physicians, and nurses—and asked them to identify what they felt were important events that needed to be charted. Not surprisingly, the most common answer was to chart every 2 hours because this was the clinical practice. As we probed past this automatic response, we found that the answers varied widely. Nearly everyone agreed that all changes in ventilator settings should be charted. However, deciding which measured variables to record was more difficult. What were lacking were agreed-upon definitions of artifact and significant event.

In Figure 4, much of the data in the raw signal would be considered artifactual by most clinicians. But, again, how is artifact defined? One leading dictionary lists six different meanings, including these three: (1) "a handmade object, as a tool, or the remains of one, as a shard of pottery, characteristic of an earlier time or cultural stage, esp. such an object found at an archaeological excavation," (2) "a spurious observation or result arising from preparatory or investigative procedures," and (3) "any feature that is not naturally present but is a product of an extrinsic agent, method, or the like."[2] Whereas the first of these definitions is probably the most familiar to the layperson, the second and third definitions are nearer the sense of artifact as it is used in describing or discussing the phenomenon in digital communication. Still, differences exist in

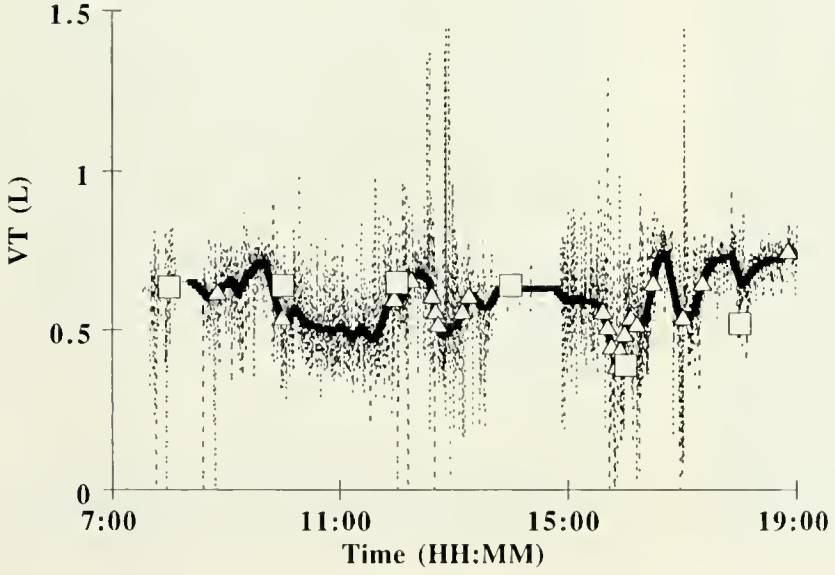

Fig. 4. An example of tidal-volume data collected from a ventilator at 10-second intervals. The effect of filtering with a LOESS filter is shown, and only the significant events are stored in the patient record. Raw data are indicated by verticle dashed lines, filtered data (LOESS filter) by heavy black line. Δ = significant events; □ = manually charted.

use of the term. One of the issues is the perspective of the observer. For example, an engineer designing a ventilator would consider an artifact to be anything that made the measured variable inaccurate, whereas a clinician would also include in his definition of artifact those values that were accurately measured but did not represent the true state of the patient.

The definition of what constitutes an artifact varies widely among clinicians. When asked for a specific definition, the clinician will typically ask about the specifics of the case and patient history. If this is any indication, then the definition of artifact must depend on the disease-patient complex and will vary not only among individual patients but also throughout the course of the disease. If this is true, then a clear definition of artifact may be very difficult to settle upon. Certainly, as mentioned above, a universally satisfactory and useful definition of artifact is lacking, and agreement may be as precious and difficult to find as artifacts from ancient Egyptian tombs.

Similar problems exist with definitions of a significant event. The problem that we encountered with defining a significant event was the end point chosen. If one chooses patient outcome as the end point, then only events that affect patient outcome are considered significant. Obviously, patient outcome is far too extreme an end point. There are no data in the literature to support a definition of what events have significant impact on patient outcome. What it boils down to is an educated guess as to what amount of change in a particular variable could potentially affect the patient significantly. An argument could be made for adjustable definitions of significance, depending on the patient's status. For example, the critically ill patient with the adult respiratory distress syndrome might be exquisitely sensitive to changes in mean airway pressure, whereas the average postsurgical patient does well no matter what the mean airway pressure is.

A different perspective on this issue is the legal one. We have sought our lawyers' opinions on how often we need to collect data to have a good legal record. The answer was circuitous, at best. They implied that we should collect data at the interval proven to be adequate. Inasmuch as an adequate interval has never been specified or proven, the next best thing would be to collect data at the same rate that everyone else does. The lawyers added the caveat that respiratory care practitioners should collect only data that they are prepared to act upon. Fetal monitoring is a good example of a situation in which it has been easy to collect large amounts of data, but if the obstetrician has not acted upon the data, he has been found to be liable. In some ways, from a legal perspective, if we are not prepared to act upon data more frequently than every 2 hours, it may be better to 'stick our heads in the sand' and pretend that nothing happens between those 2-hour ventilator checks.

One way to deal with definitions of artifact and significant event is to force the clinician at the bedside to make the decision. This is what is currently being done in many ICUs that have computer systems interfaced with ventilators. All data from the ventilators are collected at fixed intervals and displayed, either in graphs or in tabular form. The clinician is asked to retrospectively pick the valid, artifact-free, significant events for charting. We duplicated this procedure in our study by asking the clinicians to circle the points in the raw data that they felt should be charted. There was good agreement in the points chosen for ventilator settings; however, the measured datapoints chosen by each individual varied widely. It is understandable from a legal perspective that manufacturers do not want to be involved in making the decision as to what is artifact; however, it is unrealistic to expect a person at the bedside, who was not in the room when the data were generated, to retrospectively pick out the 'good' data from amongst all the noise. A slightly different version of this technique is to store automatically acquired data when someone in the room signals, by pressing a key, that the patient is in a representative state. This works well for the periods when someone is at the bedside; however, what should be done with all the data from times when no one is in the room? Should they just be ignored? Much of the research needed to answer these difficult questions remains to be done. No ventilators currently make any attempt to send only "representative" data.

Current Status

Digital communication in most modern ICU ventilators is provided at Level A (hardware) and

Level B (handshaking between devices). However, it is not often easy to accomplish even these levels. No standard exists for representation of data (Level C), and no ventilator vendors currently provide any support for data validation and checking representativeness, the two highest levels of digital communication.

Several systems are commercially available to interface with selected ventilators. Puritan-Bennett's Clinivision product interfaces directly with their 7200 ventilator. Various ICU computer systems have developed interfaces for the Puritan-Bennett 7200, the Siemens 900C and 990 Servo computer module, the Hamilton Amadeus and Veolar, the Bear 5, and other ventilators that provide digital communication ports. These are typically custom interfaces that are matched to specific ventilators. These custom interfaces can be expensive and difficult to maintain. This means that if you happen to have a computer system in your hospital and want to connect your ventilators to it, most likely you will have to spend a great deal of time and money to do so. With only about 20 new installations of ICU computer systems in 1991 in the more than 5,000 ICUs in the United States,[3] a lot of ICUs that use modern ventilators do not have computer systems. Many ventilators, therefore, have idle digital communication ports.

In some research systems, ventilators have been successfully interfaced with computers. Shabot et al at Cedars-Sinai in Los Angeles have interfaced their Hewlett-Packard ICU computer with the P-B 7200 ventilator.[4,5] In that system, data are sent from the ventilator only when the clinician at the bedside pushes a button or when a ventilator setting has been changed. Our group has set up research systems at LDS Hospital in Salt Lake City that interface computers with the Siemens 900C and 900i ventilators,[6-9] as well as with the Hamilton Amadeus and Puritan-Bennett 7200 ventilators.

To facilitate data acquisition from a wide variety of medical devices, a standardized medical information bus (MIB) has been proposed.[4] The MIB provides a local area network (LAN) around the patient that can be interfaced with all bedside devices and that allows data from each device to be stored in a central database in a standard format.[10-13] The MIB is being standardized by the Institute of Electrical and Electronic Engineers (IEEE, New York City NY) so that all hospitals and vendors can have a common data format and so that their computers can easily communicate with many bedside devices.[4] The MIB handles issues unique to medical data communications, such as automatic recognition of new devices placed at the bedside, automatic reconfiguration of the network, and association of a device with a particular patient's bedside.[4] Unfortunately, the currently proposed MIB standard does not include standards for digital communication at Levels D and E (artifact rejection and significant-event identification).[14,15] Comparing Figures 1 and 3, it is ironic that the largest amount of effort has been spent on standardizing digital communication at Levels A and B (hardware and handshaking), which are the least important to medical decision making.

A preliminary version of the MIB was installed at the 520-bed LDS Hospital in 1986 and was connected to the HELP system.[14-17] The HELP (Health Evaluation through Logical Processing) hospital information system,[18-22] which has been developed over a 30-year period, runs on a system of 12 computer fault-tolerant processors in tandem, using the Guardian Operating System. The system is fault-tolerant in that no one system problem is sufficient to halt system operation. This feature provides the system with excellent availability (it is up 99.75% of the time). Program files and patient data are stored on 14 disk drives. The 8 drives currently used for clinical purposes store 2.4 gigabytes of data, while the 6 drives used for research hold 8.8 gigabytes.

The clinical drives are mirrored (ie, two drives hold the same data), virtually eliminating the possibility of data loss by hardware failure. When accessing data from one of the mirrored drives, the system retrieves the data from the drive that has its 'read head' closest to the data, which minimizes data-retrieval time. Eighteen Charles River Data Systems (CRDS), UNIX-based minicomputers are interfaced with the HELP system. The CRDS machines serve as multiplexes and preprocessors for terminals on the nursing divisions, in Surgery, in the Pulmonary Division, and in the Medical Informatics Department. A total of 1,100 terminals and 200 laser printers are currently active throughout the hospital. About half of these are connected directly to the tandem computer; the other half are

connected via CRDS machines. All beds are fully computerized and have terminals at each bedside as well as at the nursing station. A version of the MIB links many of the medical devices in the ICUs directly to the HELP system (Fig. 5).

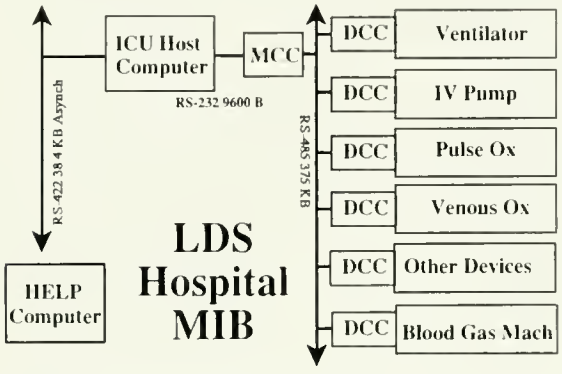

Fig. 5. The medical information bus (MIB) at LDS Hospital. A bedside network connecting many medical devices is in turn connected to a local network in the ICU and to the hospital information system. MCC = Master Communications Controller; DCC = Device Communications Controller.

An MIB interface for ventilators has been constructed at the LDS Hospital.[9] We recently completed studies investigating techniques for identifying artifacts and significant events, in which data were collected for 617 hours from 10 patients ventilated by Puritan-Bennett 7200 ventilators. Data from the ventilators were sampled at 10-second intervals and stored in a research database. This large database was then used to examine six different filters designed to eliminate artifact: (1) a moving-average filter, (2) a moving-median filter, (3 and 4) two different exponentially weighted moving-average filters, (5) a LOESS (a robust locally weighted regression technique) filter,[23] and (6) a moving-LOESS filter. Significant events were identified as values above a defined threshold (Table 3) for a critical period of time (T_{crit}). Two different T_{crit} times were used: 1 and 3 minutes. The output from each of these algorithms (a combination of a filter and a significant-event definition) was compared with the concurrent manually charted data in the HELP system.

Some differences existed between ventilator settings charted by respiratory care practitioners (RCPs) and those charted by the MIB. The error rate for manual charting of ventilator settings was

Table 3. Definitions of Significant Events

MIB Variable	Thresholds
Mode setting	Every change lasting > 3 minutes
VR* setting	Every change lasting > 3 minutes
V_T setting	Every change lasting > 3 minutes
Peak inspiratory flow	Every change lasting > 3 minutes
F_{IO_2} setting	Every change lasting > 3 minutes
Trigger sensitivity setting	Every change lasting > 3 minutes
PEEP setting	Every change lasting > 3 minutes
Plateau setting	Every change lasting > 3 minutes
Pressure support setting	Every change lasting > 3 minutes
Flow-by setting	Every change lasting > 3 minutes
Flow-by sensitivity setting	Every change lasting > 3 minutes
P_{peak}	(Change > 10 cm H_2O) *and* (3 < P_{peak} < 120 cm H_2O) *and* 1 min after ventilator mode was changed
P_{aw}	(Change > 5 cm H_2O) *and* (3 < P_{aw} < 120 cm H_2O) *and* 1 min after ventilator mode was changed
$P_{plateau}$	(change > 5 cm H_2O) *and* (3 < $P_{plateau}$ < 120 cm H_2O) *and* 1 min after ventilator mode was changed
I:E	(% change > 25%) *and* 1 min after ventilator mode was changed
Spontaneous V_T	(% change > 10%) *and* (change > 100 mL) *and* (100 < spontaneous V_T < 2500 mL) *and* 1 min after ventilator mode was changed
Machine V_T	(% change > 10%) *and* (change > 50 mL) *and* (100 < machine V_T < 2500 mL) *and* 1 min after ventilator mode was changed
Spontaneous VR	(% change > 10%) *and* (change > 5 breaths/min) *and* (0.5 < spontaneous VR < 70 breaths/min) *and* 1 min after ventilator mode was changed
Machine VR	(% change > 10%) *and* (change > 2 breaths/min) *and* (0.5 < machine VR < 70 breaths/min) *and* 1 min after ventilator mode was changed

*VR = ventilatory rate.

3%. By careful screening, we found that most of the difference came from (1) RCPs' back-charting with the wrong time-stamp, and (2) the time delay of the automated charting algorithms (1 minute for

T_{crit} = 1 min, and 3 minutes for T_{crit} = 3 min). RCPs tended to enter data and to stamp the time at which they *thought* the events occurred. Occasionally this time-stamp was in error. The error rate for manual charting of ventilator settings was reduced to 1% if all errors caused by back-charting were neglected.

Figure 4 shows an example of the tidal-volume data collected during this study. The raw data contained a lot of 'noise' and artifact. In general, all the filtering algorithms helped to reduce artifact, with the LOESS filter performing best, although it has the disadvantage that it requires much more computer time than a simple moving-median filter. The moving-median filter seemed to be the best choice because it did not follow transient events and was relatively simple to implement. There were large differences between numbers of events deemed "significant" by the algorithm and those charted manually. Two main differences were observed: (1) the RCPs did not chart what occurred when they were out of the room, and (2) when they did chart, they typically just 'took a snapshot' for a few seconds as they were working on the ventilator, which may not have been representative of the patient in the larger context.

Patient Outcome

There are few data on the impact of an automated respiratory care data-acquisition system on patient outcome. In our recent study (unpublished), we found that we could reduce ventilator-setting charting errors from about 3% to nearly zero. For measured variables, the automated charting found significant events that had previously been undetected. However, there are no data about what impact these results might have on patient care. Automation of other areas of the patient record has been shown to improve the quality of the data and to reduce the amount of time spent on charting;[24] Andrews et al reported an 18% increase in respiratory care department productivity with use of a computerized charting system.[25] However, Bradshaw et al showed that nurses' time in direct patient contact had decreased with use of computer-based data entry in the ICU.[26] Perhaps part of the problem is that computerized systems to chart respiratory care data are expensive, and one way to justify them is by a reduced requirement for employees. If these systems do save the clinician time but there now are fewer clinicians, then the net time spent with the patient may be the same or less. In general, it is assumed by most that higher quality, more timely charting of respiratory care data would improve the quality of care; however, this remains to be proven.

The Future

If digital electronic communication with mechanical ventilators is to become a routine part of clinical care, we must standardize all five levels of digital communication with these devices. A standard, such as the MIB, must be adopted to make it easy to physically connect the devices. In addition, we need more research into the elusive definitions of artifact and significant events. In the next 10 years, the respiratory care community must take an active part in this process of standardization. Without clinical input, the standardization process is doomed to failure from the beginning. Our vision is that one day, connecting your ventilator to your computer will be as simple as plugging in a telephone, and that the data will be valid and representative of the patient's true condition.

Summary and Recommendations

Although many modern ICU ventilators offer the option of electronic communication, most of these systems are not used because there is a huge communication gap between the ventilator and the computer it might be connected to. When such systems are now used, a large part of what is communicated is artifactual and misleading. We need to overcome both legal and knowledge barriers in the effort to provide seamless communication between ventilators and computers. With regard to the specific issues raised in this paper, here are our answers.

Issue #1: Is it essential to have a digital electronic communication port on an ICU ventilator?

Answer: No, it is not essential. The purpose of the mechanical ventilator is to support pulmonary ven-

tilation by supplying gas and pressure. There is no vital role for digital communication in the gas-delivery function of the ventilator; however, in the future it will be essential to have effective electronic communication in order to guarantee accurate and timely charting.

Issue #2: What impact does electronic communication between a ventilator and a computer have on patient outcome?

Answer: Our preliminary data show that electronic communication can reduce the number of charting errors and can improve the timeliness of data entry. However, there is little evidence, other than anecdotal, that this has any impact on patient outcome. Automated charting has been shown to reduce the time spent on charting.[24] This time-savings could be used to increase time spent in direct patient care, but there is no conclusive evidence that this occurs. In fact, one report on computerized charting systems indicates that the result is less time spent in direct patient care.[26]

Issue #3: If electronic communication is to be effective in the future, how should these interfaces be configured for mechanical ventilation?

Answer: We recommend an optimal algorithm for automated respiratory care charting that has been suggested.[14]

- Sampling frequency: Sample data from the ventilator every 10 seconds.
- Ventilator-setting changes: Report every new setting if change lasts more than 3 minutes.
- Measured respiratory care data:
  - Filter raw MIB-collected data with a 3-minute moving-median filter.
  - Report one filtered value every hour for each variable.
  - In addition, use a threshold table (Table 3) to define significant events.
  - Report changes that remain above threshold more than 3 minutes.
  - Report all measured respiratory-care data 1 minute following any ventilator-mode changes.

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